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FORECASTING SIGNIFICANT FOG ON THE ALABAMA COAST:

IMPACT, CLIMATOLOGY, AND FORECAST CHECKLIST DEVELOPMENT

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Introduction

The impact of widespread or locally dense fog along the central Gulf of Mexico coast may not seem as dramatic as other hazardous weather phenomena (hurricanes, for example); but its occurrence and impact are much more common. An understanding of the meteorological conditions associated with dense fog is necessary to forecast its occurrence; and moreover, such an understanding is incomplete without also considering those affected by fog, its economic impact, and extent.

For the above reasons, a fog impact study was conducted for Mobile, Alabama. The study is a preliminary evaluation of fog impact as a function of fog-reduced visibility, and the importance of variations in the areal extent of fog in the Mobile area. This information is provided along with a local climatological study of the conditions associated with dense fog in the Mobile area in order to develop a forecasting checklist.

2. Fog Impacts Along the Alabama Coast.

Aviation Services

Forecasts in support of aviation comprise a large part of routine National Weather Service operations. The National Research Council (1994) reported that one-quarter to one-half of all aviation accidents, including fatal accidents, were weather related, with an average of 440 lives lost each year. Almazan (1992) reported that 41% of all aircraft delays in 1990 were weather related, with 17% being avoidable (that is, adverse weather was forecast but did not occur). The resulting industry losses were approximately $1.7 billion. In the case of fog, although aircraft accidents may occur, the delay, diversion, or cancellation of flights is more often the result.

At the Mobile Regional Airport (see Fig. 1 site MOB), Delta Airlines reported two flights diverted or canceled due to fog in 1993. The two flights were scheduled for arrival/departure during the early and mid-morning hours. Such flight schedule changes result in losses due to the additional costs involved in shuttling passengers to and from other airports, ticket refunds, or discounts. Based on these factors, Delta typically estimates an average loss of between $5,000 and $20,000 per flight, depending on the flight affected and how many passengers are inconvenienced. Dense fog in 1993 at Mobile resulted in total losses of approximately $20,000 for Delta Airlines alone (Heying, Delta Airlines; personal communication, 1994). This figure is no doubt much greater for a major hub located in a fog-prone area.

The Mobile Regional Airport is also an operating base for several overnight package carriers who ship their freight in the early morning hours between midnight and 0600 local time. When dense fog alters air traffic, losses to such carriers include refunds for missed package delivery deadlines and the use/or storage of additional fuel. The latter is to allow for extra flight time should it be necessary to divert the aircraft to an alternate landing site.

Area hospitals around Mobile require the use of both fixed and rotor wing aircraft in the transportation of patients and donor organs to and from hospital facilities. According to the FAA (Flescher, Mobile Flight Service Station; personal communication, 1993), the local emergency helicopter services will not fly when conditions are below IFR (instrument flight rules) criteria. For example, Southflite (a local medical helicopter service operated by the University of South Alabama) can provide emergency service for local hospitals only when visibilities are two statute miles or greater in the daytime or four miles at night (Garrison, Southflite; personal communication, 1994). Johnson and Graschel (1992) identified similar impacts in the transport of offshore oil workers to and from platforms in the Gulf of Mexico.

Ground Transportation

Fog often plays a role in motor vehicle accidents when the visibility is reduced and/or when conditions vary considerably over short distances, such as in hilly terrain or along coastal highways. There are no specific criteria for visibility in fog which define safe versus unsafe driving conditions; however, under the guidelines for a non-precipitation weather hazard (NOAA, NWS, Weather Service Operations Manual, Chapter C-44), NWS meteorologists typically use a one-quarter mile visibility threshold when determining whether to issue updated short term forecasts or dense fog advisories across various forecast zones.

The majority of motorists may reduce their driving speed during adverse weather conditions, but many still drive much faster than they should for the conditions. Driving speeds are higher on interstate highways; and drivers may tend to be overconfident, even though the potential for a crash is essentially the same as for other highway systems. The potential of multiple-vehicle crashes is a major problem in dense fog situations. Multiple-vehicle crashes were defined by the state of Alabama as those accidents which occur within one mile of each other, within 30 minutes of each other, and involve seven or more separate vehicles (Parsons and Brinkenhoff; local study conducted for the Alabama Department of Transportation, 1994).

In 1992, the Alabama Department of Transportation reported fog as the primary factor in 0.8% of all reported traffic accidents in Alabama. Locally, there were 1,590 crashes involving 2, 952 vehicles, 402 injuries and 11 fatalities on the Interstate 10 corridor across south Alabama between 1988 and 1993. Along the Alabama portion of Interstate 10, 3% (or 48 multiple-vehicle accidents) were reportedly caused by fog, and four of these were reported along the Bayway—that part of I-10 which crosses Mobile Bay (Fig. 1). The Bayway accidents involved 789 vehicles, resulting in ten injuries and one fatality for the period 1988 through 1993.

A recent example of how one episode of dense fog can impact the local community was seen on March 20, 1995, when a multiple-vehicle accident (involving 193 vehicles, 91 injuries, and one fatality) occurred on the Mobile Bayway as locally dense fog shrouded the northern portion of Mobile Bay. An analysis of this accident revealed that a total of 235 people were involved (both drivers and passengers). Fifty vehicles were totally destroyed, and 114 were disabled on the twin span of bridges. Local insurance adjusters estimated the average claim from the accident was $6,633, based upon 15 randomly selected claims. Final cost analysis from local insurance reports put the dollar loss from this one incident near $1.3 million (*Mobile Press Register*, May 21, 1995).

Marine Operations

Marine operations include cargo shipping, commercial fishing, recreational boating, and other forms of on-the-water activity. All may be severely hampered by fog, which in turn impacts both local and national economies (Kotsch 1983). The relative impact is often greater when considering the maritime community, because most goods, both imports and exports, are moved by ship. Beyond the economic consideration is the safety of those involved in the operation and coordination of vessels. For example, low visibility due to thick fog can lead to disastrous collisions of both passenger and cargo ships, such as in the case of the sinking of the *Andrea Doria* in July 1956 off the mid-Atlantic coast (Houghton 1985).

The Port of Mobile handles over 1500 port calls and 35 million tons of imports and exports each year (Alabama State Docks, 1994). Operations into and out of the Mobile Bay shipping channels are coordinated by the Harbor Master's Office, the Pilot's Office (individuals who board the vessels and direct them through the channel), and various shipping companies. When dense fog develops over Mobile Bay, the Pilot's Office works with the Harbor Master in deciding whether to halt traffic through the channel and whether to close the port. The critical visibility defined by the Harbor Master in making this decision is one-quarter mile (Mobile Harbor Master's Office; personal communication, 1993).

When port operations are halted, large financial losses can occur. For example, if the cargo is held up in Mobile, payments for shipments are delayed and/or reduced (particularly if perishables such as fruit are involved). This, in combination with daily operating and maintenance costs, can lead to excessive losses that can cut into profits. Many of the local shipping companies interviewed by the authors indicated that the loss per ship per day can range from $10,000 to $20,000. When combined with the average number of ships operating in Mobile Bay, this could total nearly $100,000 per day.

3. Climatology of Significant Fog and Checklist Development

Given the economic and safety impacts of dense fog in the Mobile area, accurate and timely forecasts are necessary for their mitigation and/or prevention. Unfortunately, many fog forecasting procedures and methods are based on observations from airports; and if fog does not occur at an airport site, a forecaster may fail to realize its occurrence until problems are reported. However, as observations are typically not available from other locations, the airport observations must often suffice. Thus, the checklist developed here was based on a single site climatology using the official airport data (MOB).

The checklist must be used in conjunction with a careful analysis of the synoptic situation which sets the stage for mesoscale variations in a particular region. A number of articles outline typical seasonal formation regimes along the northern Gulf of Mexico Coast (Johnson and Rabin 1992; Lewis and Crisp, 1992). The checklist must also be compared to the standard normals of temperature and wind so that a forecaster may assess whether dense fog occurs under normal or "unusual" weather conditions.

Methodology

By international definition, fog is defined to occur when visibilities of less than 1 k, or three-fifths of a statute mile are observed (Huschke 1959). For the study period used here, a visibility criterion of five-eighths of a statute mile was used to delineate significant fog (NOAA, National Weather Service, Federal Meteorological Handbook 2, 1988). Significant fog data were collected for Mobile for a ten year period (1981-1990) and tabulated by month (Fig. 2), season, and time of day (Fig. 3). As seasonal datasets allow for a larger sample size and summarization of the conditions associated with significant fog, four seasonal fog checklists were developed. The resulting seasonal climatologies (Fig. 3) indicate a clear tendency for fog to form at night (95% of all occurrences).

Temperature, dew point, and wind direction and speed observed at Mobile during the occurrence of significant fog were then collected and plotted for the fall (September-November), winter (December-February), spring (March-May), and summer (June-August) seasons to identify potential checklist parameters and thresholds. After examining the data (Fig. 4), thresholds were established by noting the frequency with which significant fog was observed above or below various values of a given parameter. The range selected for each parameter was determined individually and according to the following sequence: the preferred time of occurrence that was associated with at least 95% of the significant fog events; the range of temperatures, dew points, and the range of wind directions associated with at least 70% of the events.

This technique was used so that the observed data defined those weather conditions associated with significant fog across a wide variety of synoptic regimes. This avoids biasing checklist development by the application of "fog-typing" schemes. Furthermore, this technique provides an increased degree of certainty in both the development and use of a forecast checklist as it describes the observed natural bounds of significant fog occurrence. It also requires a forecaster to think about the physical and causal mechanism associated with the occurrence and extent of fog. The monthly climatology of weather conditions associated with significant fog were also determined (Table 1) in order to provide a comparison with climatic normals.

4. Significant Fog Checklist

A significant fog forecasting checklist for each season was developed based on the above information. The checklists (Fig. 5) consist of the empirical frequencies (and therefore the empirical probability) of significant fog occurrence for each parameter. To use the checklist, a forecaster must consider the time of day, temperature, dewpoint, wind speed, and wind direction, as compared to their normal climatological values. The forecaster must also consider the dynamic and synoptic situation in combination with local observations to successfully predict the extent and duration of fog across the forecast region. Each season's checklist is described below.

Fall

Twenty-two percent of all significant fog events occur in the fall (Fig. 2), with more than half of those events occurring in November. An analysis of the time of occurrence indicated that 97% of the significant fall events occurred between 2100 and 0900 local time, and 90% occurred from midnight to 0900 (Fig. 3). The average and peak times of occurrence were 0500 through 0600 local time.

Ninety-five percent of fall fog events occurred when the temperatures ranged from 53.6 to 75.2F (12 to 24C) and the dewpoints from 48.2 to 75.2F (9 to 24C) (Fig. 4a). No significant fog was observed when the temperature was greater than 78.8F (26C) or less than 44.6F (7C). Climatology (1961-1990) for Mobile indicates that daily temperatures in the fall normally range from 57.2 to 78.8F (14 to 26C), whereas most significant fog events occur with temperatures of 62.6 to 73.4F (17 to 23C), as seen in Fig. 4a. When examined by month (Table 1), it becomes clear there are preferred distributions of temperature under which significant fog occurs. This finding is important in that it aids in the identification of the probable fog type associated with the observed or predicted synoptic conditions. This can be helpful in forecasting fog extent and duration.

Winter

Forty-four percent of all significant fog events (twice that of the fall) occur during the winter (December-February), with the greatest number of events occurring in the month of February (Fig. 2). Analysis of the time of occurrence shows that 91% of the winter significant fog events occurred between the hours of 2000 and 1000 local time (Fig. 3). The average and peak times of occurrence were 0400-0500 and 0700 local time, respectively. Ninety percent of winter fog events occurred when the temperature and dewpoint ranged from 44.6 to 69.8F (7 to 21C), as seen in Fig. 4b. No events occurred when the temperature was greater than 71.6F (22c) or less than 28.4F (-2C). Climatology for Mobile (1961-1990) indicates that temperatures normally range from 42.8 to 62.6F (6 to 17C). However, there is a preference (Fig. 4b) for significant fog when temperatures range from 53.6 to 69.8F (12 to 21C), and therefore it is likely that the majority of events are related to the advection of warm, moist air over the region and across a colder ground surface. An examination of monthly data (Table 1) shows this preference and suggests widespread significant fog formation.

Ninety-eight percent of the winter significant fog events occurred with winds of 7 kt or less, with 76% associated with winds from 30 to 230 deg (NNE through SW). This is clearly different from the mean wind (north at 9 kt) and implies that significant fog during the winter may have advective, upslope, and/or sea fog contributions. Monthly data (Table 1) indicate that a southeasterly wind is the key to significant fog formation as the flow passes over relatively warmer water. However, only 19 significant fog events (2%) occurred with winds greater than 7 kt, and no events occurred with winds greater than 12 kt. In fact, 70% of all significant fog events occurred when winds were from 100 through 230 deg and the wind speeds were only 3 to 6 kt (i.e., weak advection). Therefore, radiative and other contributions (precipitation, for example) are probably important factors, and perhaps necessary conditions, for the development of significant fog. This suggests there may be large variations in the formation and extent of significant fog during the winter, even though the fog may at times be widespread. These variations will be a function of local dynamics and changing synoptic conditions.

Spring

During the spring (March-May), 28% of all significant fog events occur with the greatest number (and the second highest percentage for any one month) occurring in March (Fig. 2). One-half of all spring events (52%) occur in March, whereas only 32% occur in April and 16% in May. Most significant fog events (96%) occurred between 2100 and 1000 local time and many (90%) between 2400 and 0800 local (Fig. 3). The average and peak times of occurrence were 0500 and 0600 local time, respectively.

Ninety-six percent of spring significant fog events (Fig. 4c) occurred when the temperature ranged from 53.6 to 71.6F (12 to 22C)—nearly the same as in the fall—and the dewpoint from 50 to 68F (10 to 20C). No events were observed with temperatures greater than 77F (25C) or less than 46.4F (8C). Climatology for Mobile (1961-1990) indicates that temperatures normally range from 57.2 to 78.8F (14 to 26C). Therefore, significant fog apparently occurs under a wide range of weather conditions. An examination of monthly data (Table 1), however, reveals that significant fog observations are associated with mean temperatures that are colder than normal.

Ninety-six percent of the spring significant fog events occurred with winds 6 kt or less, and just over 70% occurred with winds from 30 through 230 deg (NNE through SW) with a slight preference for winds to be from 50 through 180 deg (NE through S). These compare to a normal wind from the south at 9 kt (although in March it is north at 11 kt). This implies an advective regime similar to that of the winter season, except that air passes over relatively colder water. Monthly data (Table 1) indicate that the winds associated with significant fog are clearly not from the normal directions. For the ten-year period, only 21 (less than 5%) significant fog events occurred when the wind speed exceeded 6 kt, indicating generally weak synoptic flows were responsible. These conditions suggest (as in the winter) large variations in the formation and extent of significant fog.

Summer

Only 6% of all annual significant fog events occur in the summer (June-August), with nearly the same number of fog events occurring in each summer month (Fig. 2). Of these significant summer fog events, time period analysis reveals that 96% occurred during two periods of the day (Fig. 3): the early morning hours from midnight to 0700 local time, and during the day from 1300 to 1700 local. The average time of occurrence was 0500 local time. This was unique as compared to the other seasons, and no events were observed between the hours of 1800 and 2300. Investigation verified that many of the fog events observed between 1300 to 1700 local time followed afternoon rainshowers and thunderstorms. The early morning peak (0600 local time) was several times greater than the daytime maximum. Investigation here indicated very weak wind flow and a radiational formation regime.

Ninety-four percent of the summer significant fog events (Fig. 4d) occurred with temperatures from 68 to 77F (20 to 25C) and dewpoints from 66.2 to 77F (19 to 25C). No significant fog was observed when the temperature was greater than 82.4F (28C) or less than 64.4F (18C). Climatology for Mobile (1961-1990) indicates that temperatures normally range from 71.6 to 91.4F (22 to 33C), and therefore significant fog occurs preferentially at colder temperatures (Table 1). This, in combination with time of day tendencies, implies strong radiative and precipitation contributions to significant fog formation.

Ninety-two percent of summer significant fog events occurred when wind speeds were 6 kt or less and winds were from 240 through 110 deg (WSW through ESE clockwise). This is different from the normal wind direction (Table 1) and suggests that moisture advection is not an important factor in significant fog formation during the summer months. For the ten years studied, only eight events (8%) occurred when the winds were from 120 through 230 deg (SE through SW clockwise) and wind speeds were greater than 6 kt. These, in combination with temperature, imply remnant frontal zones (including sea breeze, land breeze, and other zones of density contrast) may be important to the development and location of significant fog.

6. Summary and Conclusions

The methodology described in this study is intended to characterize those conditions associated with significant fog and provide for the development of a local forecast checklist based on the establishment of empirically derived threshold criteria. This allows identification of a range of parameter values associated with the formation of significant local fog. In addition, this also allows an assessment to be made with regard to fog occurrence as compared to normal conditions (climatology), and with regard to fog distribution and extent.

The checklist flow chart was designed to take the forecaster from the highest probability parameter (time of occurrence—95%) to the lowest (wind direction—70%), in order to provide a higher degree of certainty as to whether significant fog will develop during the forecast period. An important limitation is that only single site observations were considered. Therefore, the application of checklist parameters in locations other than the immediate vicinity of the site must be adjusted based on local topographic features and the proximity of locations to the coast. This is essential if a forecaster is to predict the formation areal, extent, and duration of significant fog.

Although a checklist does identify those weather conditions associated with significant fog development, significant fog does occur under other conditions. It is essential that forecasters also examine numerical model output and study the synoptic and mesoscale patterns, along with all available data—including satellite imagery. Comprehensive climatological studies identifying those conditions conducive to the development of dense fog across forecast regions should ideally be made based on several sites. This would provide greater specificity to checklists and allow forecasts of the areal extent of fog, which could be more readily verified. The benefits from such an endeavor would be significant, particularly for mesoscale forecasting, as forecasters would gain a better understanding of the natural bounds unique to the development of significant fog across their forecast zones.

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Sea Transportation Company of Mobile

Star Shipping Company of Mobile

Stachan Shipping Company of Mobile

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MOBILE 30 YEAR CLIMATOLOGY VS MOBILE 10 YEAR CLIMATOLOGY

Mobile 30 YR CLIMO (1961-90)	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1. TEMPERATURE												
– Normal High:	15C (60F)	18C (64F)	22C (71F)	26C (79F)	29C (85F)	32C (90F)	33C (91F)	33C (91F)	31C (87F)	23C (80F)	21C (70F)	17C (63F)
– Normal Low:	4C (40F)	6C (43F)	10C (50F)	14C (57F)	18C (64F)	22C (71F)	23C (73F)	23C (73F)	20C (68F)	14C (57F)	10C (49F)	6C (43F)
– Mean Temp:	10C (50F)	12C (53F)	16C (60F)	20C (68F)	24C (75F)	27C (81F)	28C (82F)	27C (81F)	25C (78F)	20C (68F)	15C (59F)	12C (53F)
– Extremes:	-16 - 29C 3F - 84F	-12 - 28C 11F - 82F	-6 - 32C 21F - 90F	0C - 32C 32F - 94F	6C - 38C 43 - 100F	9C - 39C 49 - 102F	16C - 40C 60 - 104F	15C - 39C 59 - 102F	6C - 37C 42F - 99F	0C - 34C 32F - 93F	-6 - 31C 22F - 87F	-13 - 27C 8F - 81F
2. WINDS												
– Mean Speed:	10 Knots	11 Knots	11 Knots	10 Knots	9 Knots	8 Knots	7 Knots	7 Knots	8 Knots	8 Knots	9 Knots	10 Knots
– Prevailing Dir:	N	N	N	S	S	S	S	NE	NE	N	N	N

Mobile 10 YR FOG CLIMO (1981-90)	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1. TEMPERATURE												
– High:	20C (68F)	21C (70F)	23C (73F)	21C (70F)	23C (73F)	23C (73F)	27C (81F)	27C (81F)	25C (77F)	27C (81F)	23C (73F)	21C (70F)
– Low:	-3C (27F)	3C (37F)	8C (46F)	10C (50F)	16C (61F)	18C (64F)	19C (66F)	21C (70F)	19C (66F)	11C (52F)	0C (32F)	-2C (28F)
– Mean:	12C (54F)	14C (57F)	15C (59F)	16C (61F)	19C (66F)	21C (70F)	23C (73F)	23C (73F)	22C (72F)	20C (68F)	17C (63F)	13C (55F)
– 90% or Greater Fog Occurrence Temp Range:	3C - 20C 37F - 68F	8C - 20C 46F - 68F	10C - 21C 50F - 70F	12C - 22C 54F - 72F	17C - 24C 63F - 75F	18C - 24C 64F -75F	20C - 26C 68F - 79F	21C - 26C 70F - 79F	19C - 25C 66F - 77F	15C - 25C 59F - 77F	12C - 23C 54F - 73F	3C - 20C 37F - 68F
2. WINDS												
– 90% or Greater Fog Occurrence Speed Range:	< 8 Knots	< 8 Knots	< 9 Knots	< 8 Knots	< 8 Knots	< 8 Knots	< 7 Knots	< 6 Knots	< 8 Knots	< 8 Knots	< 8 Knots	< 8 Knots
– 70% or Greater Fog Occurrence Direct. Range:	20 - 220	50 - 230	40 - 260	40 - 290	30 - 230	30 - 240	270 - 90	310 - 100	30 - 260	10 - 200	40 - 230	30 - 190
– Prevailing Dir:	SE	SE	SE	SE - W	NE	NE	NW - N	NE	NE	ENE	SE	SE

Table 1. Thirty- and ten-year monthly climatology (1961 - 1990, 1981 - 1990) for MOB. Temperature and wind data based on all observations in comparison to significant fog observations.

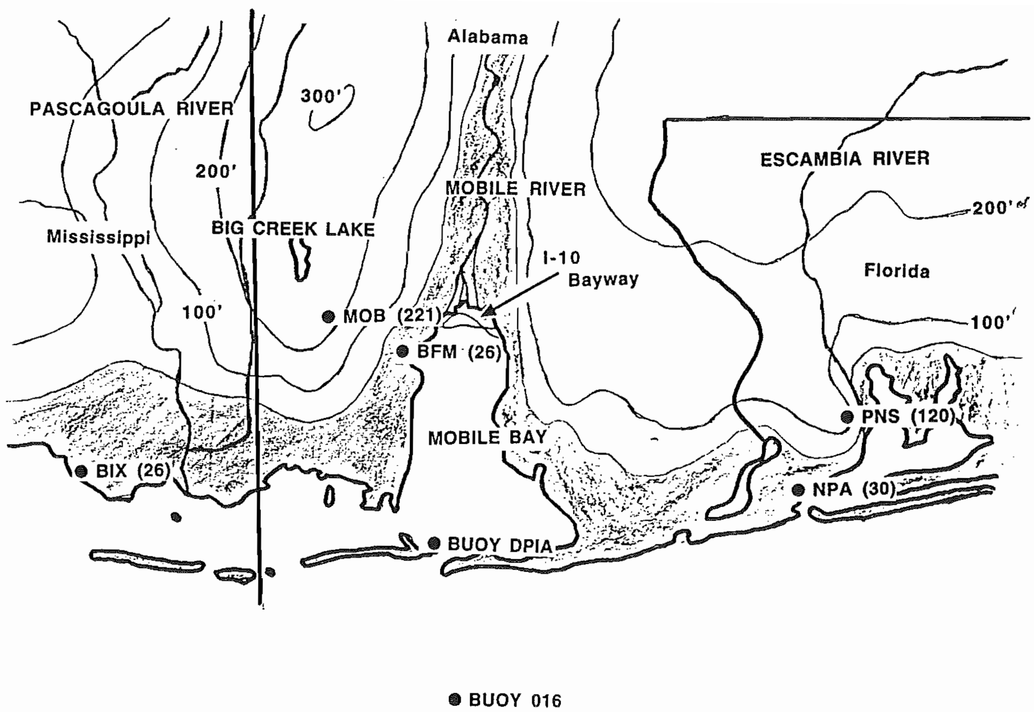

Fig. 1. Topographical and political map of the Mobile Bay area. Contours show every 100 feet elevation mean sea level. Hatched area indicate elevations less than or equal to 50 feet mean sea level. Local reporting stations (MOB, Mobile Regional Airport; PNS, Pensacola Regional Airport; BIX, Biloxi's Keesler Air Force Base; NPA, Pensacola Naval Air Station; BFM, Brookley Field Mobile; BFM, Brookley Field Mobile; DPIA, Dauphin Island CMAN platform DPIA1; Buoy 016, Bouy Station 25016) are also shown.

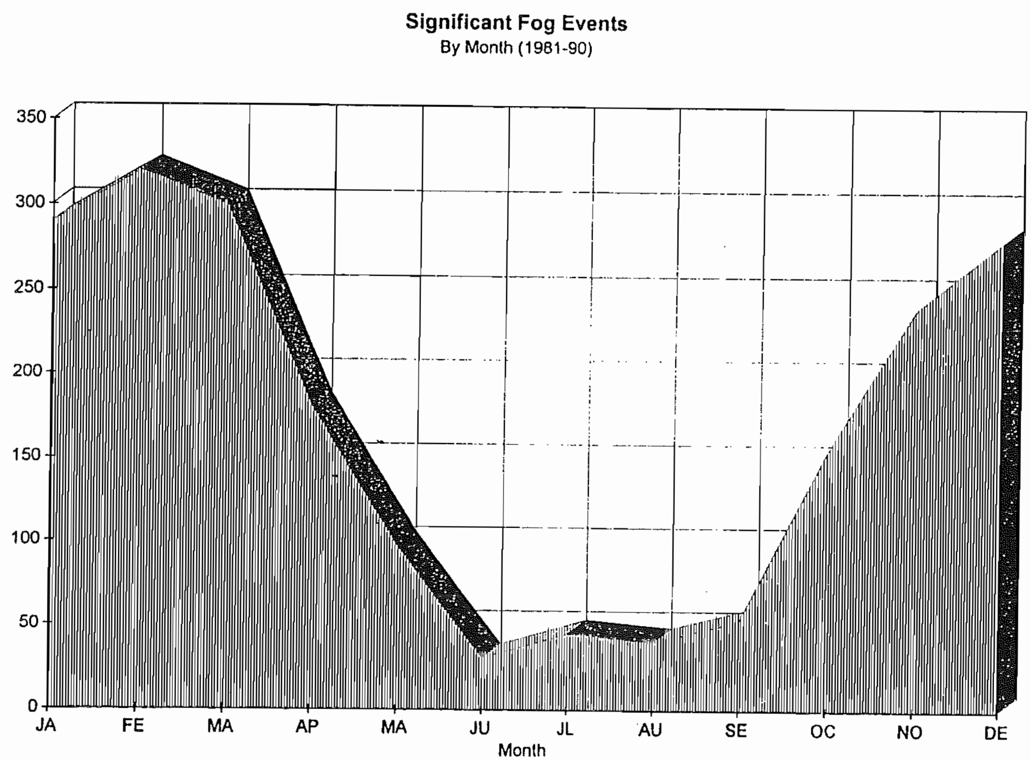

Fig. 2. Frequency of significant fog by month for MOB based on the period 1981 - 1990.

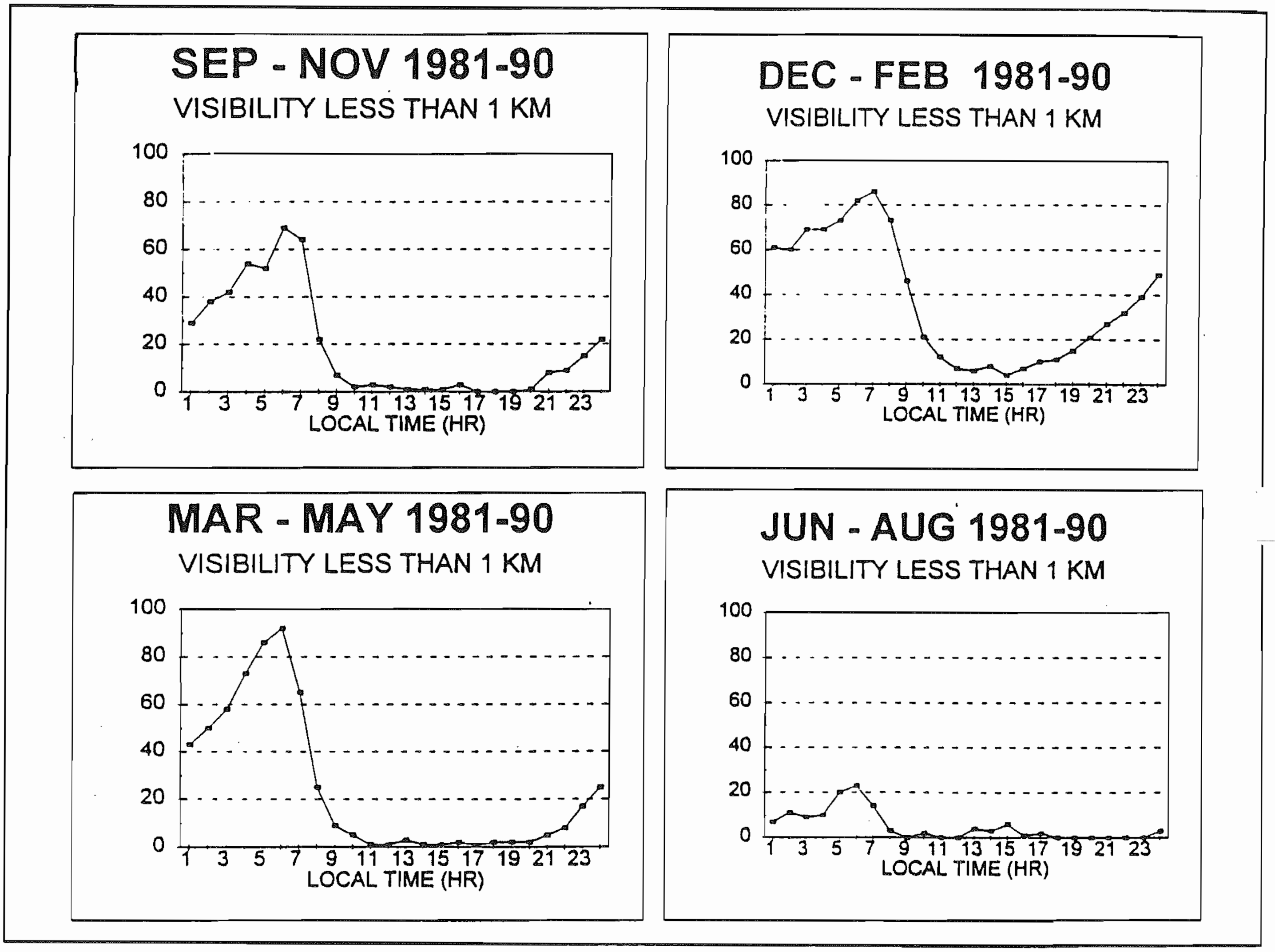

Fig. 3. Frequency of significant fog (defined as visibility less than one kilometer, 5/8 of a statute mile) by hour of day for each season at MOB for the period 1981 - 1990.

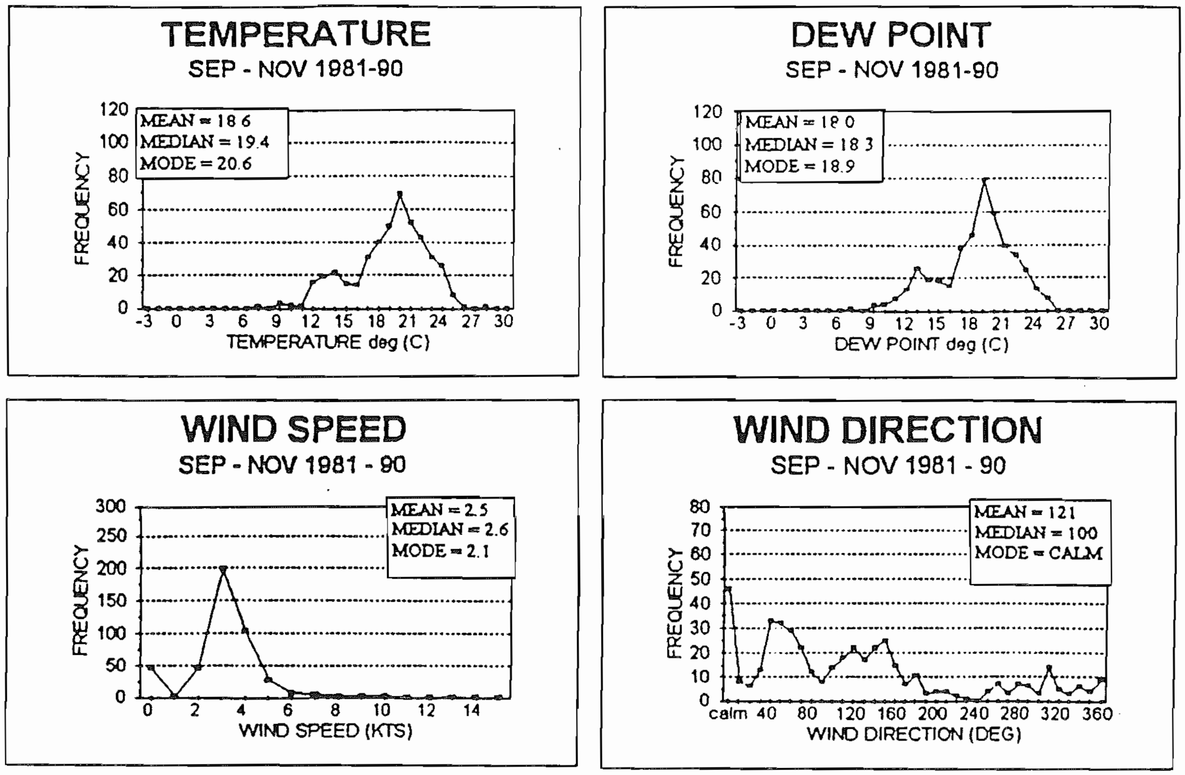

Figure 4a

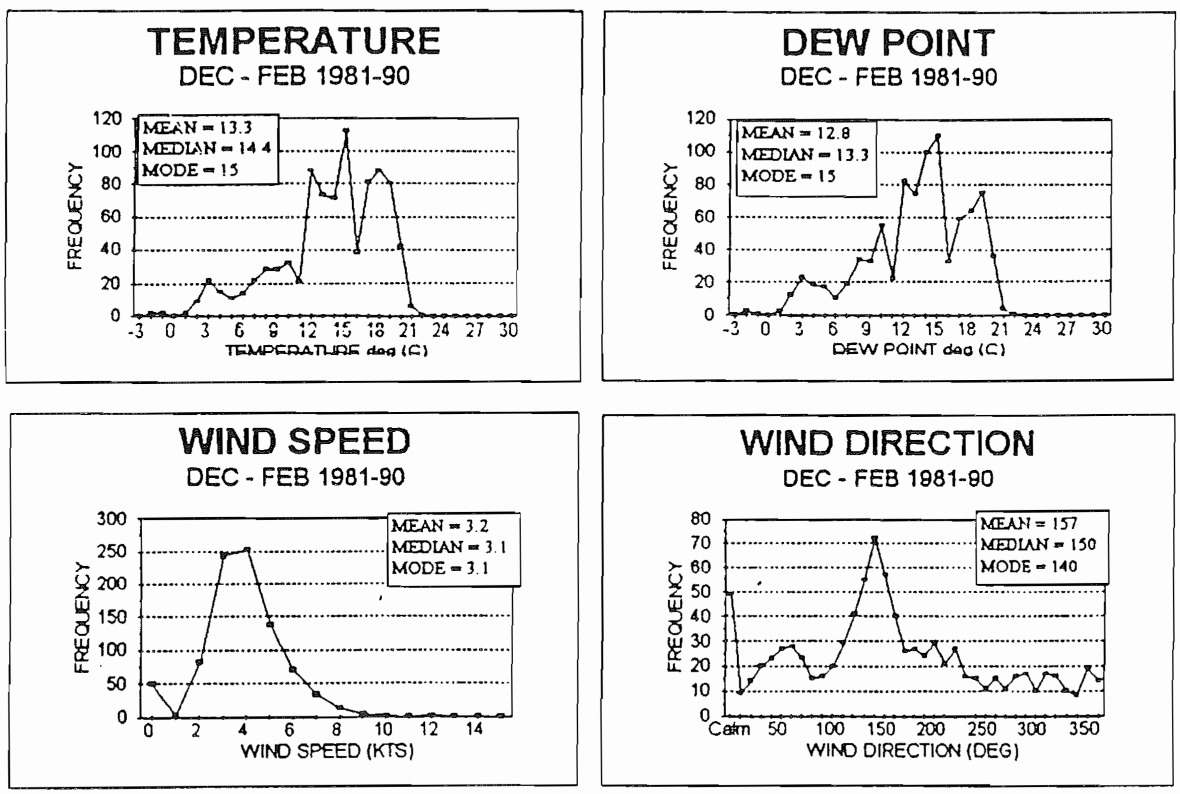

Figure 4b

Fig. 4. Frequency distributions of temperature (C), dewpoint (C), wind direction (degrees), and wind speed (knots) observed at MOB simultaneously with significant fog by hour of day for the **(a)** fall (Sep - Nov), **(b)** winter (Dec - Feb), **(c)** spring (Mar - May) and **(d)** summer (Jun - Aug) seasons for the period 1981 - 1990.

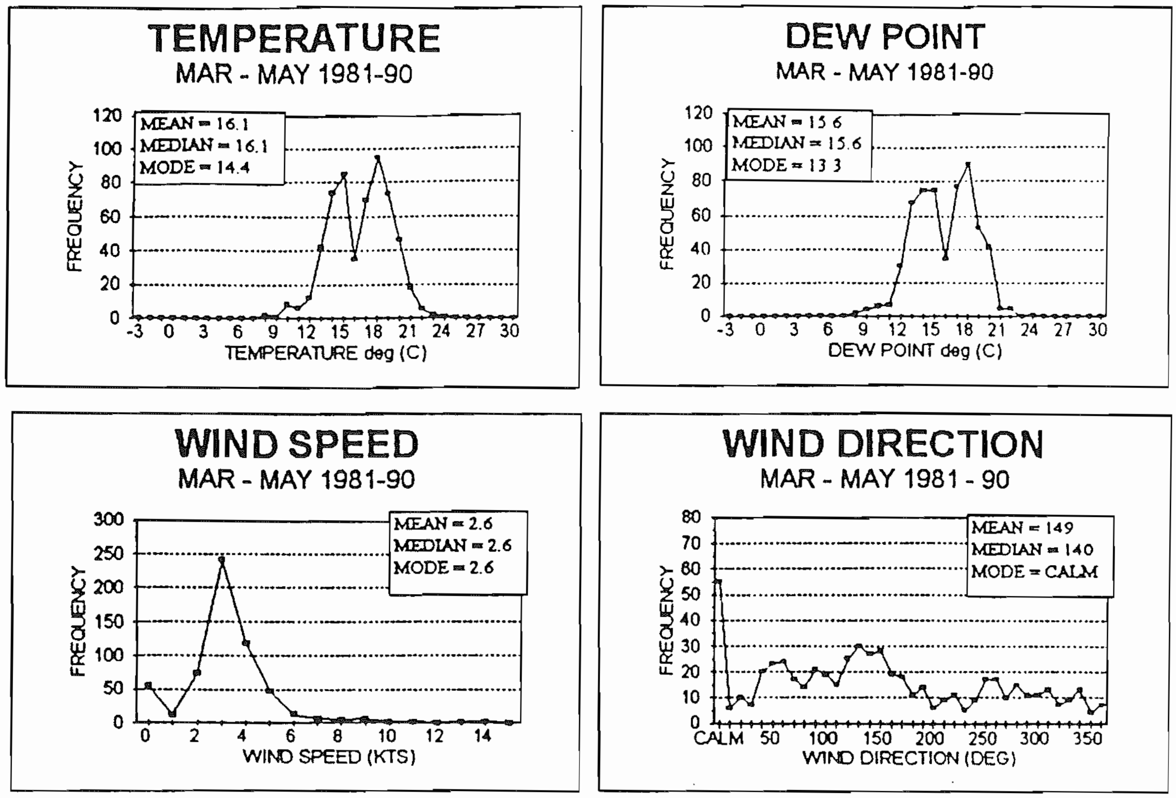

Figure 4c

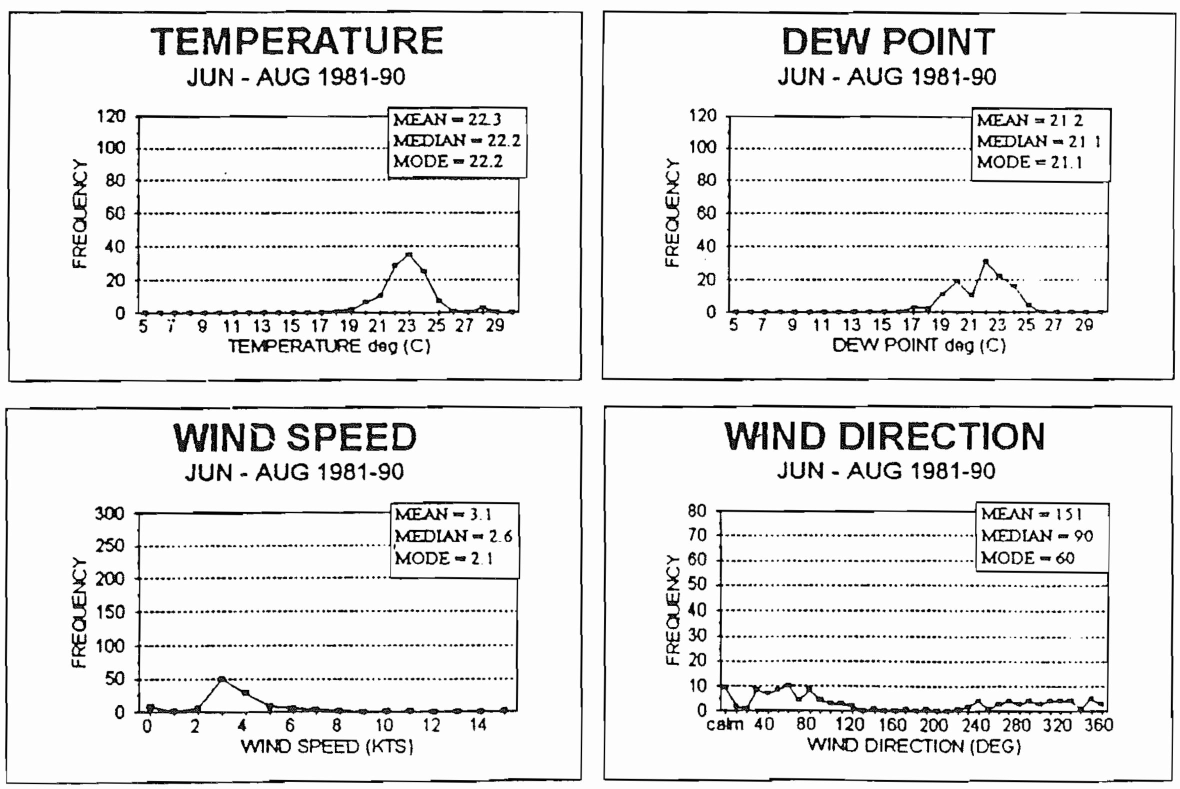

Figure 4d

Fig. 4 cont.

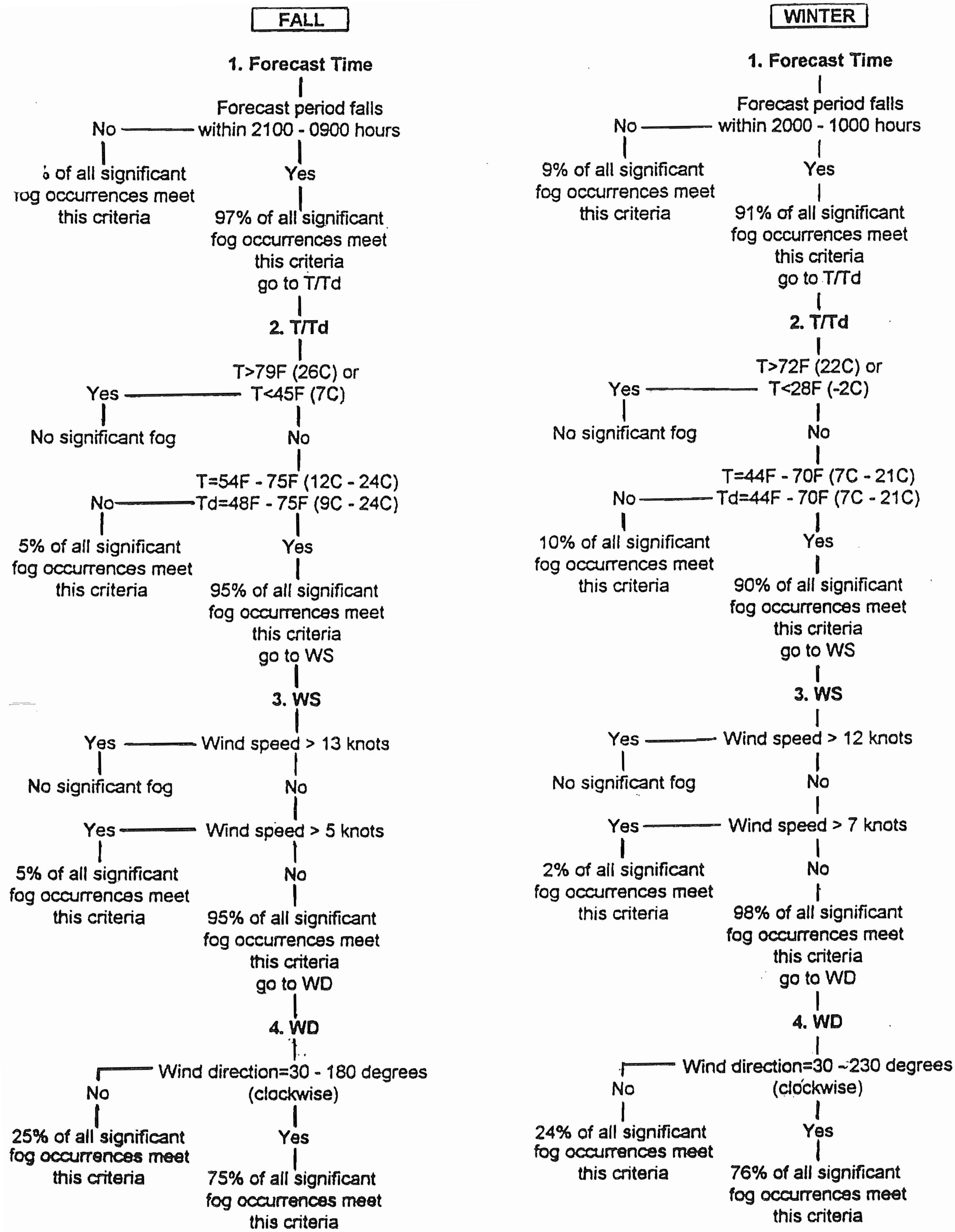

Fig. 5. Significant fog forecasting checklists by season for MOB.

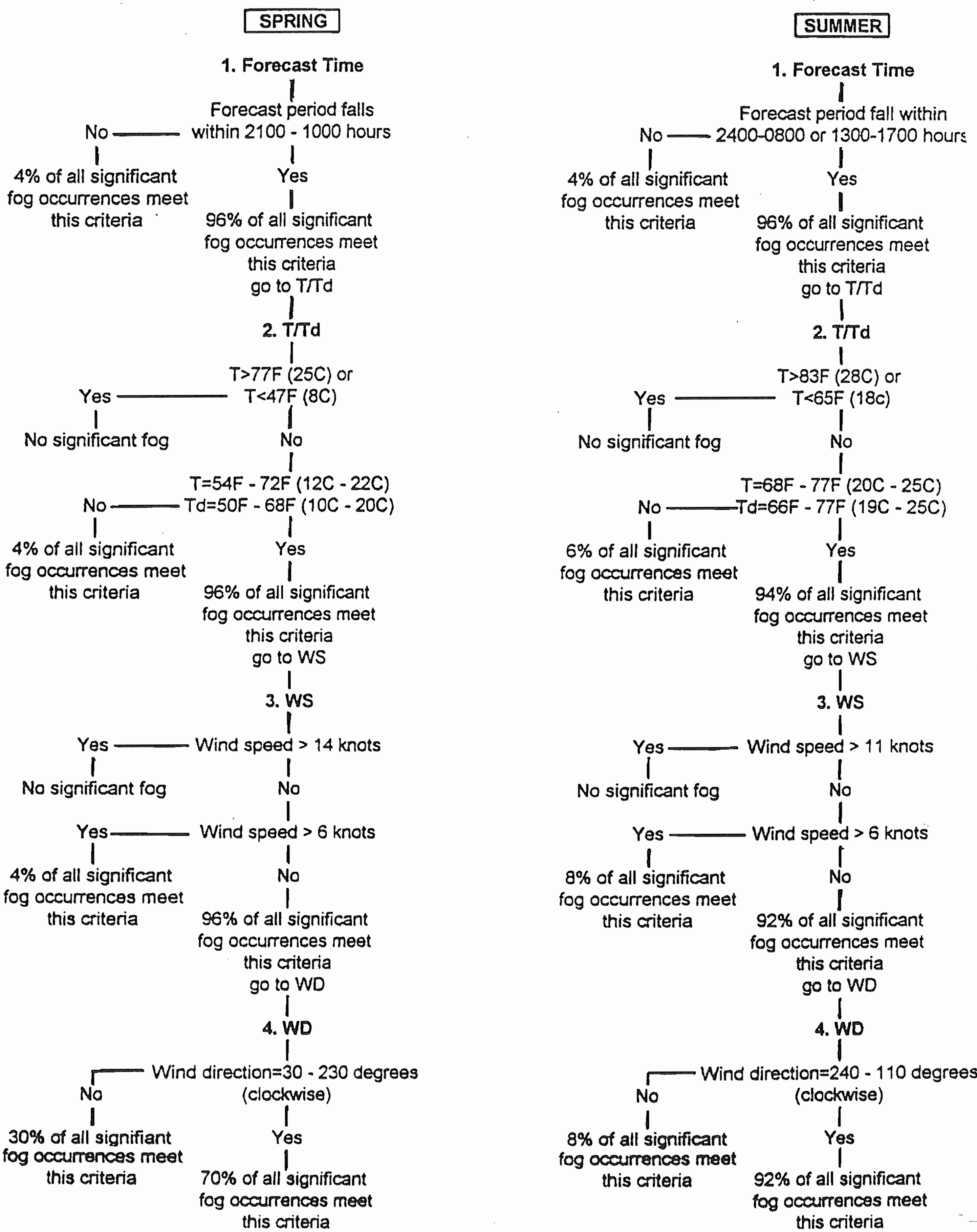

Figure 5 (cont)